

A GIS-BASED PATH SEARCHING SYSTEM FOR TRANSIT NETWORKS

SUN Zhuo
Master Course Student
Dong-A University
Hadan-Dong, Saha-Gu, Busan,
604-714 South Korea
Fax: +82-51-205-5187
E-mail: sunzhuo@gmail.com

YANG Zhongzhen
Professor
Dalian Maritime University
1 Linghai Road, Ganjingzi, Dalian
116026, China
Fax: +86-411-8472-6756
E-mail: yangzhongzhen@263.net

Abstract: This study aims to seamlessly integrate transit network with road network in GIS and searching the best transit path between origin and destination (OD). Unlike previous studies, the Transit Route Table and Connectivity Matrix no longer need to be built. The system uses dummy links to combine the road and transit networks to a single network which can represents the real world and traveler behaviors much more effectively so that the development and maintenance of database become easier. Because of the uniformity of its network topology, an ordinary shortest path searching algorithm can be embedded and utilized without any modification. By considering many factors that could affect the travelers' travel and using GIS platform, this system can provide users with friendly interfaces and display visual, feasible and precise results.

Key Words: integrated network, transit network, best path, shortest path algorithm, GIS

1. INTRODUCTION

Transit systems are an important component of intelligent transportation systems for reducing traffic demands, which helps to reduce traffic congestion and energy consumption, thereby alleviate the air pollution. However, it is not always easy for people to use transit system around a metropolis. The problem is not about availability of services, but about finding a travel plan for a trip. Finding travel plans for non-recurrent trips from a wide selection and combination of bus, subway, and train routes is not an easy job even for local people, let alone tourists. Demands for non-recurrent trips may occur when there are special events and when services for the commuters' customary travel plans are interrupted or detoured under unexpected situations. A transit advanced traveler information system (TATIS) can meet the needs mentioned above, and GIS can be used as an effective interface in TATIS to manage transit systems and display information friendly and visually. It is essential for TATIS to offer travelers the accurate and reliable transit information and let them know the actual operation situation, such as the needed time/cost, the transfer times and transfer sites. At present most large cities developed their own TATIS, in some cities the systems are even installed in the street-stand information or Internet terminals (Lu, 2001).

The purpose of this study is to develop a GIS based path searching system on the transit network as a part of TATIS. It can provide users with an accurate best path on transit network when given an origin and destination. Many previous researches have undertaken such work before. At present, there are several types of path searching system as follows:

- 1) GIS is applied to display inquiry results or not in the system. Transit Route Table or Connectivity Matrix is built from the information provided by the transit company, such as stops, ticket price, time, etc. Users can get transfer information through Route Table. The transfer information provided by this method is inaccurate and indirect. The

increment of transfers results in the increase in matrix dimensions by arithmetic progression and therefore, this method is usually used to calculate those inquiries which have less than 3 times transfers.

- 2) GIS is totally applied as the user interface in the system, and the topological structure of a transit network under GIS is formed. Route Table is stored at each stop or presented in the form of Connectivity Matrix. The shortest path from the origin to the destination is calculated by using the modified Shortest Path Algorithm (SPA) along with Route Table or Connectivity Matrix when users inquire. The result of this algorithm is direct and accurate but the SPA and transfer algorithm are complicated and the maintenance of Route Table is difficult.
- 3) Roads and transit routes are combined under GIS (the bonding point is called junction). The others are similar to the second type of system mentioned above. This method can provide more accurate information, such as walking route between stops, transfer fare, etc., and the SPA and data structure are more complex and the maintenance of system becomes more difficult.

In order to take the advantages and overcome the shortages described above, a renewed approach was carried out in this study. By using a raster image as the background, the road network can be founded. A transit route network then can be constructed over it. The road network and transit lines are integrated seamlessly into a large integrated network. Unlike previous researches, here Route Table and Connectivity Matrix are dismissed entirely and dummy links will play a vital role when connecting two networks. All factors that affect the travel plan are stored in the attributes table of the integrated network. This can greatly simplify the data structure and make it very direct to be accessed so that the SPA does not need any changes. The difficulty of development and maintenance of databases and the system is reduced.

2. NETWORK STRUCTURE

2.1 Construction of Networks in GIS

The popular method adopted to build the road network on GIS is shown in Fig. 1.

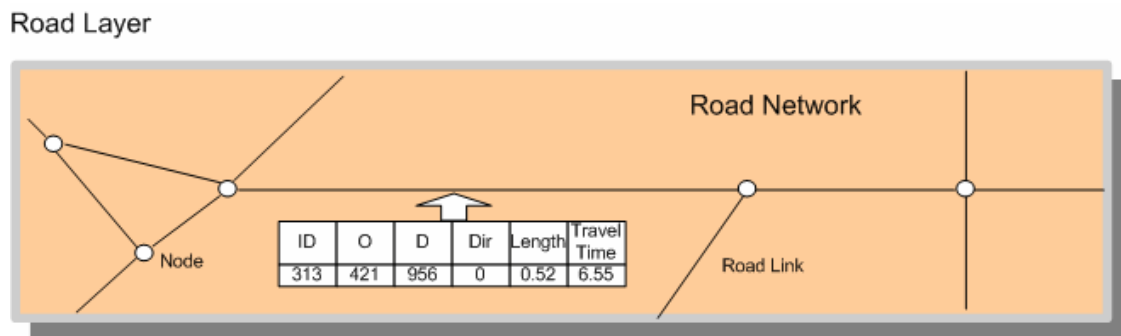


Fig.1 Road Network Built on Road Layer

First, road layer is created based on raster image, above which the topological structure of road network is built. The attributes of road links is calculated by using spatial function of GIS and stored in the road network directly. The item of Length can be gained through the length of the vector "polyline" in GIS and then divided by the scale of the raster image. The Length unit is set to kilometer. The item of Travel Time can be gained through the average

walking speed (5km/hour) and the length.

The transit network is stored on an independent layer over the road layer. Transit lines can be created by referring to roads lines. Then stops can be built on the lines according to their real location, and then the lines are split by the being created stops. Finally connect lines segments and stops to form a transit network.

The data structure of links in the transit network is similar to the links in road network as shown in Fig. 1 except for the item of Travel Time. It can be calculated according to the real road property and the transit mode. For example, there is a bus route in the network. The route's Travel Time can be obtained based on bus speed (about 30km/hour as usual) and the route length. Therefore, the value of Travel Time in a bus link is one sixth of the overlaid road link. If the ticket price increases along with the increasing of mileage during transit, the ticket price should be converted to equivalent time by using an appropriate formula. This issue will be discussed later.

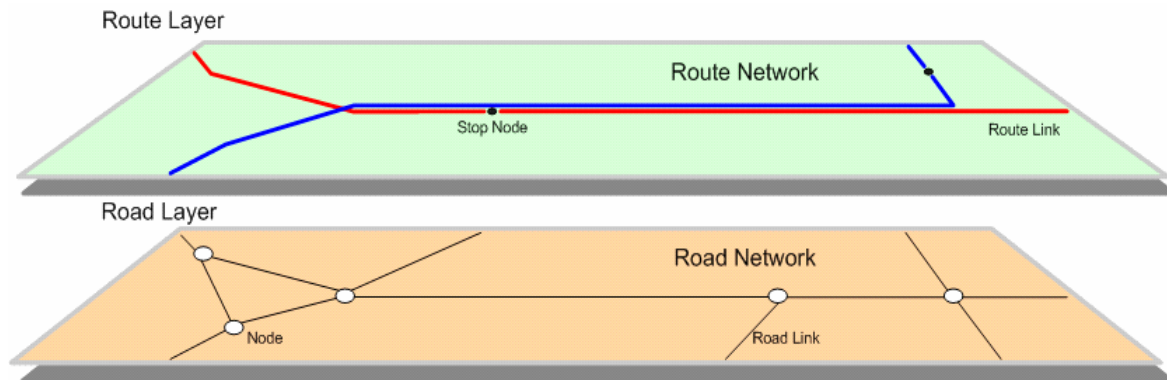


Fig.2 Transit Network based on Road Network

There are some points should be noticed when forming the topological structure:

1. If many transit routes have their stops at same location of a road, these stops cannot be merged into one node. Each link should be split by its own stop node. Therefore, the transit route network is formed by many connected links that are parallel to each other. (Distances are 0)
2. All routes in the transit route network and all roads in the road network should be converted to one-way link to match the "bigraph" topology. In practice, a two-way road or route can be presented by two directed links which are parallel and have opposite direction. After that the first principle also should be considered for setting up stops on each link.

Since the road network and transit route network are based on a raster image as the background, its accuracy becomes significant for the system. It would be better to use a photograph with high resolution taken by a satellite or a plane, and the road network and transit route network can nearly match the real world and the inquiry results would be very accurate for users. Dada such as vehicle performance, road capacity, etc. provided by transit enterprise and road companies should be used as much as possible to calculate the links' impedance in the road network and transit route network.

2.2 The Combination of Road and Transit Networks under GIS

After road network and transit network are built, they need to be integrated in order to perform further calculation and analysis. The popular methods are that integrate stop nodes in the transit network and the nearest intersection nodes in the road network, which is: firstly from every stop node on the route layer find the nearest intersection node on the road layer; and then the ID of stop nodes is substituted by that of intersection nodes. This method of integration is very simple by using spatial functions on GIS. But it still has some disadvantages:

1. There are rarely bus stops that are built near the intersection of roads in the real world, because this would influence traffic flows. As a result, the total system error generated from this method would be significant.
2. The pattern of integration is simple but will lead to inconvenience for future calculation and analysis. Not only the network impedance, such as waiting time, transfer penalty, etc., should be stored in extra matrices or tables but also these matrices and tables need to be considered to calculate the equivalent network impedance and create the connectivity for the transit route network when a network analysis algorithm is applied. This makes those algorithms very complex and makes developers take more effort to perform further development on it.

The method shown in Fig. 3 is used by our system to integrate the two networks. Firstly all of stop nodes on the route layer are directly projected to the road layer correspondingly at the same coordinate and split the overlaid road link. Then, each one original link becomes two links that are connected through the projected stop node. If some projected stop nodes on road layer are quite closed to each other (<5m), the frequent splits will lead to a partial complex structure. Now these nodes on the layer of road can be integrated into one node. The “many-to-one” mapping between the nodes in the transit route network and in the road network is formed (Fig.4). After that, the nodes in transit network and road network are linked by using dummy links (Fig. 3 & 4). Those dummy links include two parts: one is the access link. It starts from the node in the road network and goes to the corresponding node in the transit route network. The counterpart link of an access link is called egress link. These two links can find correspondences in the real world: the access link corresponds to the behavior of getting on vehicles and the egress link corresponds to the behavior of getting off vehicles. The two links' impedance Travel Time could be calculated through the following formula:

$$Ta = t_w + t_b + w \times t_c, Te = t_d \quad \text{Eq.1}$$

Where Ta is the value of Travel Time of an access link, t_w presents waiting time. t_w can be calculated through the interval between departures provided by the transit enterprises. If buses or trains depart every 10 minutes from their terminal then t_w should be equal to the average waiting time, 5 minutes. t_b presents the required time spent on getting on a vehicle from the outside of a stop. It depends on the structure of the stop. For instance, traveling by subway, it requires 2 minutes including the time one spend getting down from over-ground to underground and the time one spend getting on a train from the platform. t_c presents the time converted from the ticket price.

$$t_c = \frac{\text{ticket price} \times \text{legal annual working time}}{\text{annual income per head}} \quad \text{Eq.2}$$

w is weight used to adjust the percentage of time after conversion. If users do not mind the transit cost but want to arrive at the destination as soon as possible, w can be set to 0. T_e presents Travel Time of egress links and it is equal to t_d , which is the time one spend getting

off vehicles plus getting out of the stop.

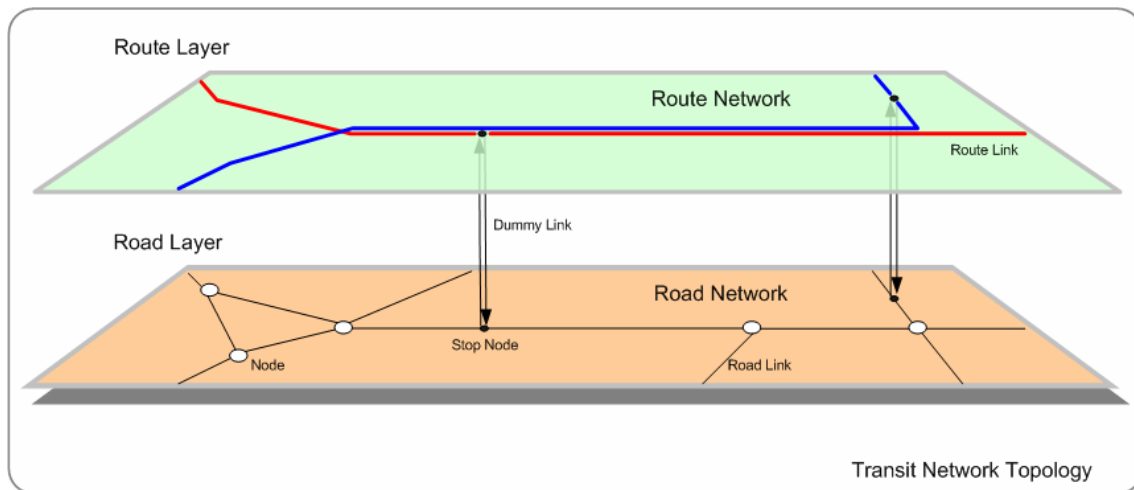


Fig.3 Combined Network of the Road Network and Transit route Network

The combined network includes all of the expenses which travelers will expend to make a trip. Those expenses, such as time, fare and physical strength, could convert to unified impedances at corresponding links in the combined network. This form of network can present the real world more vividly than previous methods. It can make the maintenance and analysis of this network much easier. More accurate and efficient enquiry results could be provided to users.

3. ALGORITHM OF PATH ENQUIRY

Since the completely new model is adopted to integrate road network and transit one, the whole topological structure matches the real situation very well and the path inquiry algorithm becomes more accurate and simpler. Fig. 5 shows the flow chart of the enquiry system, the input part based on GIS can guide user point to the origin and destination nodes on the digital map. This will not be explained in detail in this chapter. Here the analysis algorithm for path inquiry will be concerned.

3.1 Data Structure and Weights

It's necessary to build the data structure in computer memory before inquiry. Since the final merged structure of this research is only a simple bigraph, the process of building data structure becomes very simple. Just reading the nodes and links in the road network and transit one and inserting them into a list in computer memory by order can make it. The users can determine the weights of various links with user interface before the program read link impedance from the network to the memory. The final impedance values are equal to the value that Travel Time multiplied by the weight. For example, users want to walk on less distance, reduce the time of getting on and off and reduce the number of transfers due to his heavy luggage. He can set up a higher weight for the link of road network and dummy link. Thus the higher values could be gotten through the value that Travel Time multiplied by weight inputted and the user will get a result path in which there are smaller walking distance and fewer transfers.

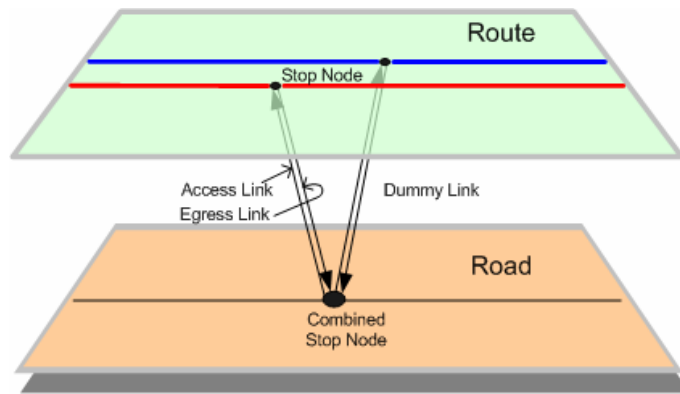


Fig. 4 Amplified Topological Structure with Many Stop Nodes at Same location

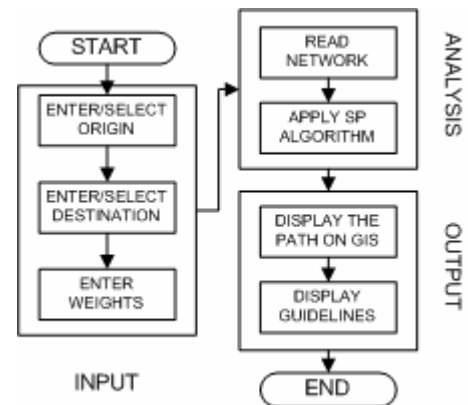


Fig. 5 Flow Chart of the System

3.2 Applying the Shortest Path Algorithm

Existing researches did not completely combine road and transit networks but use a modified version of Shortest Path Algorithm along with Route Table and Connectivity Matrix. Thus the process generating an optimal path is very complicated. The data structure produced in our study is just a bigraph; therefore, any standard Shortest Path Algorithm can be applied directly without any adjustment. Here, Dijkstra's SPA is used to search the shortest path in the integrated network. The algorithm has been optimized and the cost time on analyzing a large network is no more than 1s; this can satisfy the needs of users for real time request.

3.3 Analysis Results

The path between OD calculated with SPA is in the integrated network, including walking path, transit path and transfer path. Fig. 6 shows a transfer behavior in a searched path. It can be seen that the integrated network can consider the impact of transfer to the whole trip perfectly. The transfer will be automatically divided into three steps, namely access, walking on road network and egress. During analyzing the integrated network to generate the optimal path, if a bus stop appears as a node, the algorithm will search for all of the links connected to it, and the optimal path spanning tree will be extended. The nearest stop around the egress link in the road network and the next stop in the transit network will be considered at first and then the algorithm will continue. It is unnecessary for system developers to concern about how much impedance should be set up for transfers in the transit network, because the access link, egress link and the walking path between stops can make it. System developers just need to concern how to get the impedance in the network more like the behavior taken on by users in the real world. Those factors can be taken into account automatically by the path inquiry algorithm and the resulted path must have the smallest sum of impedances due to the existing of those factors.

The resulted path will be displayed to users in two ways: one is displaying it visually through the friendly graphic interface on GIS; the other is providing a text instruction to guide users' traveling. If the combined network has built precisely on GIS and has load a precise raster image as its background, user can print out the result and use it as an accurate guide for the travel. The actual travel route will coincide with the resulted path.

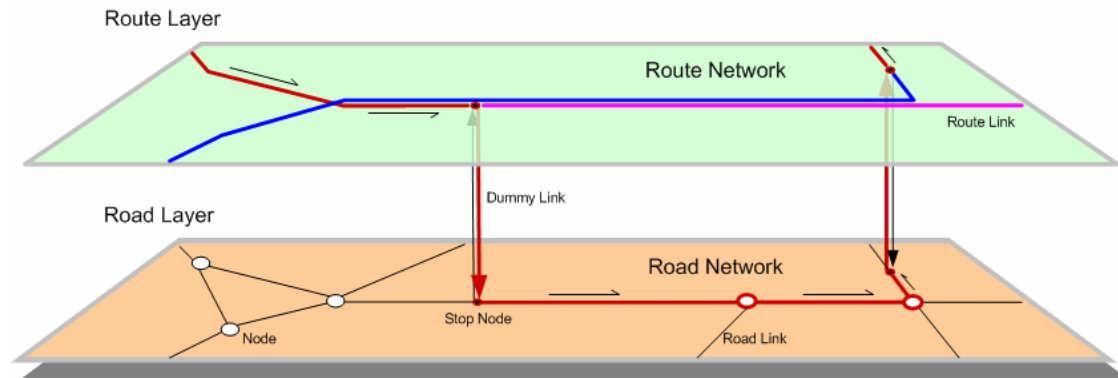


Fig. 6 A Typical Transfer in The Combined Network

4. CASE STUDY

4.1 A Simple Case Tested on GIS Platform

In order to test the validity and feasibility of our new network structure and algorithm, an ideal and simple case has been built first. The road network is built on MapInfo (a popular GIS platform) as a gray grid (16×9) shown in Fig. 7. The impedance of each road link is set to 1000. The bold colored lines in the map are transit routes on the route layer. They have stops at every intersection of the overlaid road network. The impedance of every route is set to 100. All of the links on both networks are bidirectional and the two networks are merged by dummy links. The impedance of every access link is set to 200, and every egress link is set to 50. The method in section 2 has been used to combine the two networks

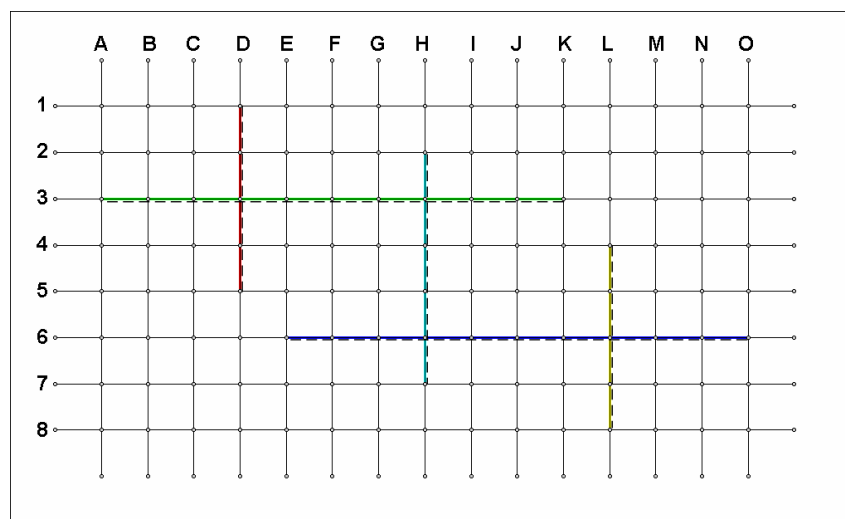


Fig. 7 Integrated Network in GIS (gray lines present roads, bold colored lines and dashed present transit routes)

Fig. 8 displays the searched path calculated from an arbitrary path inquiry request. The origin node (E1) is at the top left of the map and the destination node (M7) is at the right bottom. The bold black line represents the result. It shows that the searched path in this case is as good as expected. The searched path in the combined network calculated with SPA automatically considers the effect of walking, transit and transfer during the whole trip. If a

user follows this path he will walk from E1 to D1 then get on a bus at D1 and go to D3 along the transit route D1-D5. At D3 he will transfer to another transit line and then at H3, H6 he will make a transfer likewise. Finally he will get off the bus at M6 and walk to M7. The total impedance of this optimal path is 4400.

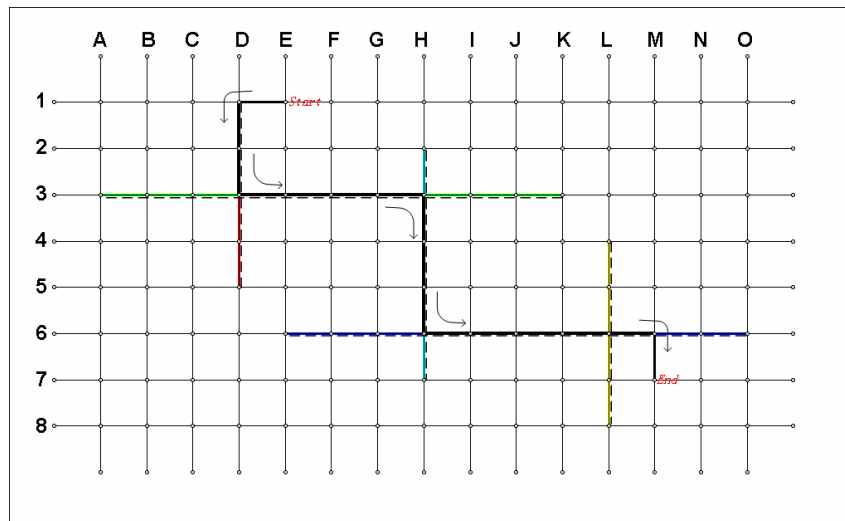


Fig. 8 A Searched Path on GIS (the string “Start” and “End” denote the origin and destination of this path)

If a user wants less transfer, he can use a factor to multiply the access link. For instance, a user sets the factor to 5, then the impedance of every access link become to $200 \times 5 = 1000$. And the optimal path between the OD will be E1-E3-K3-L3-L4-L7-M4. The number of transfer becomes 1 and the total impedance becomes 8000. Other typical cases have already tested on the integrated network. For example, for the case of a rain day, the weight of walking link in road network can be increased and the congestion condition can also be represented with changed impedance of transit links, etc. Those modifications do not affect the stored properties of the network and the algorithm. The system just need to change the factors of each link when copy them to the computer memory. All results follow our theory very well.

4.2 An Application for a Real City

It also needs to test a more complicated network in a real world. TransCAD is a system for transportation data management and analysis and fully integrates GIS with planning modeling and logistics applications. In its demonstration package there is a map contains a road network and a transit network. This map can be used to demonstrate its embedded Best Transit Path algorithm on the integrated transit network. Since both the network structure and the best path algorithm are complicated in TransCAD, then a new network structure and algorithm are used to establish a new path searching system.

This map has five layers: node, streets, route system, stops and physical stops. The “streets” layer contains all of the roads in the city and stores their intersection nodes on the “node” layer. The “route system” layer is composed of 10 two-way transit routes and stores its stops on “stops” and “physical stops” layer. The impedances in the two networks have been set well and should be reliable. So it needs to just combine the two networks with dummy links and apply the Shortest Path Algorithm.

Fig. 9 shows a searched path from an arbitrary inquiry request. The origin node is at the top left and the destination is at the right bottom. The zebra line in the middle represents the optimal path. The dialogue window at the top right displays guides for used transit.

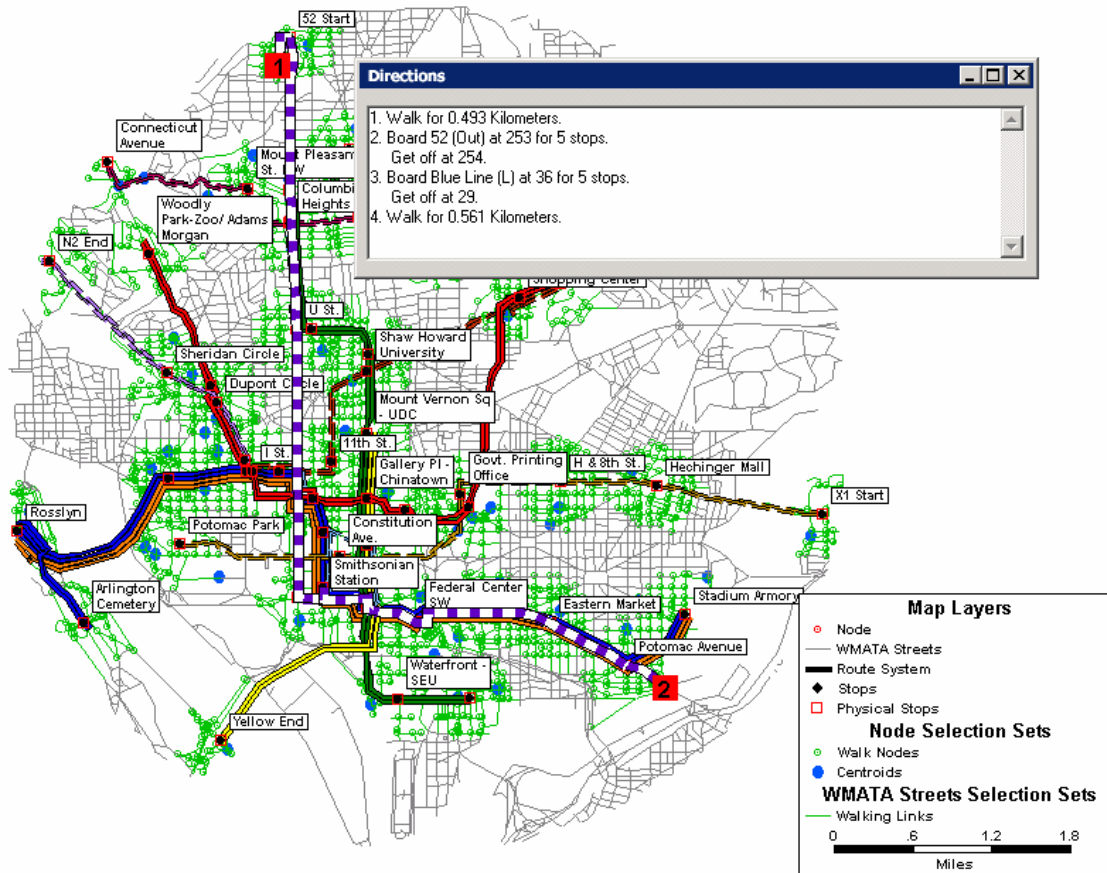


Fig. 9 A Searched Path in TransCAD

After comparing the results generated by our system with those generated by embedded function in TransCAD, it can be found that the result paths are identical when the Weight and Travel Time are set to the same values which can be found in the embedded function, but the setting procedure of embedded function in TransCAD is quite complex and it is hard for it to consider some special problems. For example, the convenience rate of getting on/off at each transit stops and the impedance of links between stops varying due to the local terrain. To realize these functions TransCAD must allocate new memory space to store extra matrices and modify the best path algorithm in order to represent those situations. However, to realize them, our application just needs to add a factor in the formula which has been used to calculate the impedance of links in the integrated network. Then with SPA the inquiry can be carried out, and the inquiry is very simple and does not need user to determine two many options. Because of the flexibility of our network structure and the independency between the network topology and path inquiry algorithm, researchers could alter the formula which can set the impedance of dummy links to get many new features in our system.

5 CONCLUSIONS

Similar to the above application, a typical city could use this system based on the existing road and transit networks since it uses dummy links to connect road and transit networks to

imitate the real world. This method makes the whole network structure visual, simple and effective, although it may increase the data volume and the needed storage space. The algorithm for path inquiry can be deep simplified due to the structure, and any standard module of Shortest Path Algorithm can work on it. The total enquiry system could be taken part into two independent parts. The maintenance and development of the whole system become much easier. System developers may improve the system further in two aspects.

1. Make the integrated network more accurately to imitate the real world more vividly.
2. Improve the path inquiry algorithm to provide more reliable and detailed information.

To achieve the first goal, a more accurate raster map may be used as background to regulate the digital map in GIS. The impedances stored in the integrated network can be updated by filed survey or dynamically updated by ITS. More factors which will affect the travel can be taken into account before user inquiry, such as weather, congestion rate and comfort rate.

To achieve the second goal, more standard path analysis algorithms can be utilized on the integrated network. Because of the uniformity of the integrated network, every standard algorithm for bigraph can be used directly. Now this system just uses a standard Shortest Path Algorithm to perform the inquiry request. In the near future, the k th Shortest Path Algorithm is planned to be realized on this system. It will provide many alternative paths to users so as to let users choose the best paths fitting for their needs more freely.

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